III. "Experiments on a Fundamental Question in Electro-Optics: Reduction of Relative Retardations to Absolute." By JOHN KERR, LL.D., F.R.S. Received March 9, 1894.

To prepare the way, I begin by recalling these well-known facts: that when light passes through an electrostatically strained medium in a direction perpendicular to the line of electric force, it undergoes a uni-axal double refraction, the optic axis coinciding with the line of force; that with reference to this action, dielectrics are divisible into two classes, the positive* and the negative,† which are optically related to each other in the same way as the positive class of crystals to the negative; that the intensity of the action, or the quantity of optical effect per unit thickness of the dielectric, is measured by the product CF^2, where C is a constant which is characteristic of the medium, and P is the value of the resultant electric force: that the effects are generally observed and examined still as they were discovered first, by simple experiments with a pair of Nicol's prisms and a slip of strained glass or other phase-difference compensator.

In every such experiment the effect specified by the compensator is a difference of phases, or a relative retardation; and we may therefore view it as a resultant effect—that is to say, as the resultant, or the difference, of electrically-generated absolute retardations of two component lights, whose planes of polarisation are parallel and perpendicular to the line of electric force. What, then, are the values of these two absolute retardations in any given case? *What are the two absolute components of any electrically-generated relative retardation?* Such is the question here proposed for solution by experiment.

As long ago as 1882, and several years following, I was much occupied at intervals with this interesting question. In the summer of 1885, in some experiments with the dielectric CS_2, I obtained results as decisive as could be desired. Other dielectrics, both solid and liquid, were tried afterwards, but only with partial success, the experimental difficulties being, in some cases, too much for my methods and time. To these cases I shall make no further reference, as I will keep to the one line of experiment, and to those experiments in particular in which the indications were quite regular and unmistakeable. With these limitations, the inductions extend to four liquid dielectrics, two positive and two negative; and all the experiments point clearly in one direction.

General Result.—It appears that the proper and immediate optical

* Carbon disulphide, the hydrocarbons, &c.

† Amyl oxide, the heavy oils, &c.

effect of electric strain is a positive or negative retardation of the one component light whose plane of polarisation is perpendicular to the line of force, the sign of the retardation being, of course, the same as the nominal sign of the dielectric. Therefore, of two vibrations which are (on Fresnel's hypothesis) perpendicular and parallel respectively to the line of force, it is only the latter that is immediately affected by the electric strain, this *vibration along the line of force* having its velocity of transmission *retarded* or *accelerated* according as the dielectric is of the *positive* class or the *negative*.

I venture to regard this result as a general law of double refraction in electro-optics, though the proof extends only to four different dielectrics. As the best proof that I can offer, I will merely give a condensed historical sketch of the experiments. It will be seen in this way how the law was first suggested and then confirmed by the phases of a new electro-optic effect. It will be seen also that the proof of the law is independent of all hypotheses, independent even of everything previously known in electro-optics.

The Plate Cell is a piece used in all the experiments. There is an

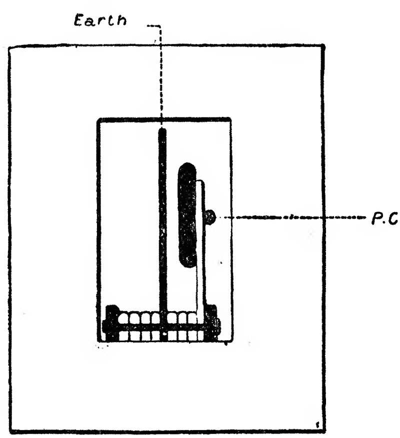

Fig I.

end-view of it given in the adjacent figure. It consists of five slabs of plate glass, each 10 in. by $7\frac{3}{4}$ in., arranged face to face in one block. The inner rectangle represents a tunnel ($5\frac{3}{4}$ in. by $3\frac{1}{4}$ in.) which passes right through the block. Inside are shown the conductors with supporting frame, the shaded pieces being of brass, and the unshaded of plate glass. The lengths of the conductors, at right angles to the plane of the figure (and parallel to the light), are $6\frac{1}{2}$ in. and $7\frac{1}{2}$ in., the thickness of the cell being nearly 8 in. By means of wires, which pass through the wall of the cell, the internal conductors are con-

nected with prime conductor and earth, as indicated in the figure. It is understood, of course, that the surfaces of the two conductors are well planed and polished, all corners and edges rounded off, and the two fronting faces accurately parallel. The cell is closed, in the usual way, by panes of plate glass laid against the ends, and the whole block is kept together by a screw-press. Two borings in one of the plates provide for the filling and emptying. When the cell is put in order and charged with CS_2, and examined according to the old method (with a pair of crossed nicols), it gives a very pure double refraction, and acts well in all respects, except that (from deficiency of insulation) the largest effect is less than might be expected, hardly amounting to one average wave-length of relative retardation. But this defect is of no great consequence.

The First Experimental Arrangement is shown in the next diagram, in horizontal section through the lamp L and the observer's eye E, but without strict regard to scale.

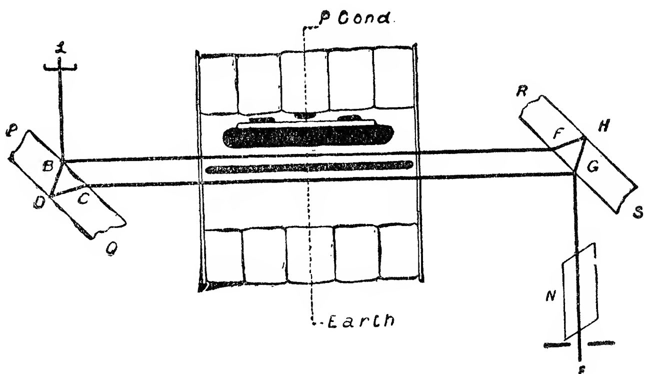

Fig 2.

Two $\frac{1}{2}$-in. plates of glass are represented in section by the rectangles PQ, RS. Their function is the same as that of the two plates in Jamin's interference refractometer.* The plates are, therefore, parallel-surfaced, and of accurately equal thickness, and are silvered on the back as mirrors; and in their working positions they are almost exactly vertical and parallel, and at 45° to the light. A pencil of light, LB, which passes through a vertical slit in front of the lamp, is incident on the first plate at B, and is divided, in the manner shown in the diagram, into two pencils, BDCG and BFHG; and from G the light proceeds anew as one pencil, and passes through a narrow circular diaphragm,† which is fixed at E in front of the observer's eye.

* Preston's 'Theory of Light,' p. 157.

† Or, otherwise, through a telescope.

The result of the arrangement is that, when the pieces are properly placed, the bright vertical slit L, as seen from E in the direction EG, is crossed by a set of interference-fringes. These are well defined in position by reference to a constant black line, the image of a fine wire which is fixed across the slit L. It may be assumed, without argument, that any small increase or decrease of velocity of one of the pencils BF, CG, will produce a positive or negative displacement of the fringes, at the rate of one fringe-width of displacement for every wave-length of relative retardation. As far as the assumption is required, it is easily verified by the introduction of thin plates of glass into the course of the light, anywhere between the two thick plates; and I find in this way, definitely, that (as the pieces actually stand in the diagram and in all the experiments) an ascent of the fringes indicates a relative retardation of the pencil BF.

There are two essential pieces that remain to be noticed, of which the first is the electro-optic cell. It is shown in the diagram how the laterally separated component pencils pass through the cell, BF through the electric field, and CG through the space electrically screened by the second conductor, this conductor being always to earth. The last piece is a Nicol's prism N, which is placed in the path of either of the single pencils GE, LB, with its principal section laid (1) horizontally and (2) vertically. The design of the apparatus will now be apparent, which is to give the means of detecting electrically generated changes of velocity of the light BF in two successive cases, when the plane of polarisation is (1) perpendicular to the lines of force, and (2) parallel to the lines of force. But in actual experiment there is a difficulty encountered at once, which appears at first sight to be insurmountable.

Disturbance of the Fringes.—Suppose all the pieces placed as in the diagram, the cell nearly filled with carbon disulphide, the second internal conductor put permanently to earth, and the fringes obtained in good form and position. When connexion is made between the first internal conductor and the knob of a charged Leyden jar whose outer coating is to earth, there is an immediate disturbance of the fringes, a set of large and irregular movements, with deformations, ending in the disappearance of the whole system in one or two seconds. The effects are seen better when the first internal conductor is connected permanently with the prime conductor and an attached Leyden jar, for the potential can then be raised regularly and very slowly from zero, and the full course of the disturbance takes a longer time; but in other respects the phenomena are the same as before.

When the fringes have been extinguished in this way by the electric action, it is easy to recover them, either by putting the prime conductor to earth, or by keeping the potential at a sensibly constant

value, high or low, for a little time. If with this view the machine be kept working at a constant rate throughout the experiment, the extinguished fringes return gradually into the optical field, and in a little time (twenty to eighty turns of the plate) they are as clearly visible as they were before disturbance; their forms also are good, and their positions approximately constant, though they do not often continue quite motionless in such circumstances, even for a fraction of a second. If the prime conductor be now put to earth for a little, and the experiment be then repeated, the disturbance passes through all the same phases as formerly, though it is more violent at starting as the preceding interval of rest is longer. All these effects come out equally well with common light, and with light polarised in the two principal planes.

This optical disturbance is evidently a remote effect of the electric action, produced immediately—not by electric strain—but by irregular changes of density in the medium. We know that in the present cell, as in every like arrangement, the electric action throws the liquid into currents, which pervade all parts of the cell and are very intense at high potential. These material currents explain the changes of density; for, at starting, they give rise to a rapid process of mixture, forcing denser masses upward into the course of the light, &c., and, afterwards, when the mixture is completed, they are still accompanied by irregular variations of pressure in the liquid. It should be easy, therefore, to imitate the effects by means purely mechanical; and of this I can give an example from actual observation.

A plate cell, about an inch thick and open at the top, was charged with water, and placed in the course of the pencils BF, CG, immediately behind the electro-optic cell; and the fringes were obtained in good form and position. The stirring of this water gave a set of optical effects that could not be distinguished from the former disturbance. And when the fringes, extinguished in this way mechanically, were well restored and made moderately steady by regular stirring kept up for a time, I found that a disturbance of the same kind could be obtained at pleasure, either by an interval of rest (the longer the better), or by the addition of a little warm water. But leaving this and returning to the electro-optic experiments, I proceed to show how, in spite of these irregular movements of the fringes, and in the midst of them all, it is possible to obtain a steady effect, which corresponds perfectly to the known bi-refringent action of the medium.

Regular Dislocation of the Fringes.—The electric arrangements are the same as formerly, the two internal conductors being connected permanently, the first with the prime conductor, and the second with earth. There is only one change made in the apparatus; the nicol

N is withdrawn, and a small rhomb of Iceland spar (about 3 cm. long) is put in its place at E, with principal section horizontal. In this way the two systems of fringes which were given by the nicol N in succession are now given simultaneously, side by side, and each the exact prolongation of the other; the successive systems (α) of the next diagram are changed into the double system (β, γ).

The machine is now set in motion. The system (β, γ) is disturbed as was the system (α) formerly; but in the midst of the disturbance, and as long as the fringes are clearly visible, the sets (β) and (γ) are

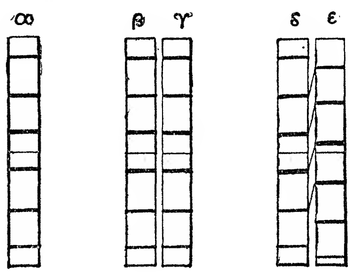

Fig. 3.

seen to be relatively displaced, the system (β, γ) being changed into the system (δ, ϵ). The extent of the dislocation increases as the potential rises; that shown in the diagram, which is about three-fourths of the fringe-width, is not much below the highest that can be got with the apparatus. The direction of the dislocation is constant, and indicates a relative retardation of that vibration in the electric field which is parallel to the line of force; and this agrees with the known character of the medium CS_2 as a positive dielectric.

It is very interesting to watch the two sets of fringes (δ) and (ϵ), and to see them sometimes moving rapidly and very fitfully, but moving always as one system, with its two parts dislocated unchangingly, except so far as the extent of the dislocation varies with varying potential. It is equally interesting to see the effect of spark-discharge of the prime conductor, especially from high potential. At the instant of the spark there is a sudden disappearance of the dislocation, an extremely quick jump of the fringes into line with each other, and this without perceptible check or sudden change of any kind in the disturbance-motion common to the two sets at the time. The best way of observing the effect is to take sparks from prime conductor to earth at stated intervals, while the machine is kept working at some constant rate. The dislocation then

reappears immediately after each of the sparks, increasing regularly from zero as the potential rises, and then increasing and decreasing quickly or slowly as the potential rises and falls quickly or slowly. Even when the potential falls most rapidly, as in spark-discharge, the direction of the backward jump is always evident to the eye; otherwise the disappearance of the dislocation in that case is so very quick that one would call it instantaneous.

Very little need be said upon the optical theory of these phenomena. What must be remembered is, that each of the sets of fringes (δ) and (ϵ) is due to the interference of two such pencils as BF and CG re-united in GE, the vibrations being horizontal in one pair of interfering pencils, and vertical in the other pair. With regard to changes of refringent power which are due to mechanical disturbance, it may be assumed that these are independent of the direction of the vibration: both pairs of pencils are therefore similarly and equally affected at each instant, and the corresponding displacements of the two sets of fringes are at each instant similar and equal, however irregularly they may vary from one instant to another. It is otherwise with the bi-refringent action of the medium; for here the two pairs of pencils are differently affected at each instant, and the difference is determined solely by value of potential, so that the corresponding effect comes out steadily in the midst of all the irregular changes which are produced by mechanical disturbance of the dielectric.

I think it must be admitted that in this regular dislocation of the fringes there is a new and clear presentment of the double refraction which is produced by electric strain. I think also that the new effect is made all the more suggestive by the regularity and perfect steadiness with which it comes out in the midst of the disturbance.

First Appearance of the Law.—Before leaving the present experiments I must notice one or two facts observed, but not yet mentioned, that go towards a solution of the question with which we started. The phenomena to which I refer were seen clearly enough in some of the earlier experiments; but it was only at a later stage that they were well understood, and they were then obtained more regularly.

Beginning with the last form of the experiment—that with the rhomb of Iceland spar as eye-piece. The spar, I should mention, was always so placed that the plane of polarisation in the set of fringes (ϵ) was vertical. What I have to notice now is a peculiar feature of the jump of the fringes at the instant of discharge. To a carefully strained, as to an unstrained, attention, this jump appeared as a movement of the set of fringes (ϵ) down to the level of the set (δ), never as a movement of the set (δ) up to the level of the set (ϵ). I must say, however, that the accuracy of this perception or judgment was to myself in some degree doubtful, not because of any expectation that could have led to it, but because of the very fugitive character

of the phenomenon, and its partial obscuration in many cases by disturbance.

Returning, therefore, to the first form of experiment, that with the nicol N as eye-piece. When the principal section of N was horizontal, and the vibration directed therefore along the line of force, there was a perfectly regular jump of the fringes downwards at the instant of discharge; and at high potential the effect was large and strikingly distinct. When the principal section was vertical, there was nothing regular of this kind seen in any of a large number of observations: there were disturbance-movements at or about the instant of discharge, as before and after, but nothing that could be accepted as a regular jump of the fringes at that instant, always in one direction or always in the other. The interpretation of these results is obvious. I have already stated, as a matter of observation, that a rise of the fringes indicates a relative retardation of the pencil BF which passes through the electric field. From the downward jump of the fringes in one of the two cases, we infer therefore that the pencil BF is in that case relatively accelerated in consequence of discharge. But in the present experiment, and with reference to the pencil BF in relation to the pencil CG, it is evident that relative acceleration and absolute are equivalent; because it is only in that division of the cell through which the pencil BF passes that there is any sudden physical change at the instant of discharge. It appears, therefore, that to relieve the liquid of electric strain, is to relieve one of the vibrations (that along the line of force) of an absolute retardation, leaving the perpendicular vibration unaffected.

In several of the later sets of these experiments with CS_2 as dielectric, and with nicol N as eye-piece, I got what appeared to be a perfectly clean liquid. The potential also was made to vary regularly and very slowly; and from both causes the disturbance was very much reduced. The effects then were these:—Principal section of N horizontal: a slow ascent of the fringes during the process of charge, pretty regular, but often obscured and sometimes overpowered by disturbance; the contrary jump seen always at the instant of discharge. Principal section of N vertical: irregular, and generally very small oscillations of the fringes during the process of charge; but no regular motion in one direction or the other exclusively, either during the process of charge, or at the instant of spark-discharge from high potential.

From all these experiments with CS_2, it seems to follow that of the two principal vibrations, the only one immediately and regularly affected by electric strain is that along the line of force. This conclusion requires and well deserves to be verified; and I proceed to verify it by another method, or rather by the use of new means.

The Second Experimental Arrangement.—The optical instrument

here used is known as Jamin's Interference Refractor for polarised light. For a description of it I might refer to a paper already published;* but I think I ought rather to describe the apparatus here again. The essential pieces are shown in horizontal section in the following diagram.

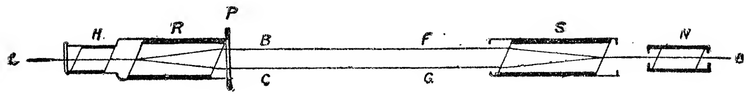

Fig. 4.

R and S are large blocks of Iceland spar, of equal thickness, their principal sections horizontal, and their faces parallel. A pencil of light from a vertical slit L, passes through a Foucault's prism H, and is polarized by it at 45° to the vertical, and then enters the rhomb R. The two pencils emergent from R pass immediately through a half-wave plate P, so placed as to interchange the two planes of polarisation. Ordinary pencil and extra-ordinary in the crystal R become thus extra-ordinary and ordinary in S, and the bi-refringement action of R is neutralised by that of S. The light enters R and leaves S as a single pencil, but between P and S it passes as a couple of pencils, BF and CG, about 14 mm. apart, and polarised in planes vertical and horizontal. The pencil emergent from S is received at E through a Nicol's prism N, which is laid as for extinction with the Foucault H. When all the pieces have been properly placed, the slit L is seen crossed by a set of interference-fringes, and these are modified at pleasure by fine screw movements of the spar S.

The electro-optic cell is not given in the diagram. It is the same piece as that shown in the diagram of the first arrangement, and is placed here exactly as there, so that the two laterally-separated component pencils pass normally through it, BF through the electric field, and CG behind the second conductor.

The only other optical piece employed in the experiments is a Jamin's Glass Compensator,† which is placed immediately in front of the spar S; it enables the observer to specify small differences of retardation of the pencils BF and CG.

The results obtained formerly (with nicol N as eye-piece) were fully verified with the new apparatus. The method finally adopted as the best was so similar to the former, and the effects also, that any long description of the experiments would be superfluous. But to give a fair view of the results I will describe one day's work.

* "On the Bi-refringent Action of Strained Glass," 'Phil. Mag.' for October, 1888.

† Preston's 'Theory of Light,' p. 159.

Final Experiments with CS_2.—The first internal conductor connected permanently with prime conductor without Leyden jar, the liquid quite clean, and the conditions of electric work perfect all day. The observations were taken in five successive sets.

First Set.—Plane of polarisation of the pencil BF (through the electric field) vertical, or perpendicular to line of force: Rise of fringes indicates relative retardation of that pencil. When the fringes were obtained in good form and position, the machine was started, and kept working at a constant rate throughout the experiment. As formerly, the first effect was a large disturbance, the fringes being displaced and deformed, and disappearing altogether at the second or third turn of the plate; but in a little time (thirty or forty turns) they reappeared in good form and approximately constant position. For distinctness of effect the central fringe was brought back to the line of reference (generally downwards) by a small screw movement of the spar S; and then, at every spark from prime conductor to earth, there was a quick downward jump of the fringes, the effect being as distinct as possible from the irregular and slow and generally small movements that went on before and after the spark. As the experiment proceeded the liquid was more thoroughly mixed, the disturbance decreased, and the effect came out much more purely. Sparks were taken repeatedly at every 3rd, 5th, 10th, 15th turn of the plate, and the jump was there in every instance, and beautifully distinct. The extent of the jump varied from about one-third of the fringe-width at every 5th turn of the plate to about three-fourths at every 10th turn. I should add that the disturbance movements, though they were greatly reduced at last, were still such as to prevent any good static observation of the fringes.

It is proved clearly by this set of observations that when the plane of polarisation is perpendicular to the line of force the light is absolutely retarded by electric strain. The spars R and S were now turned round LE through 180°, and the pieces were moved across the optic bench into good position.

Second Set.—Plane of polarisation of the pencil BF (through the electric field) horizontal: Rise of the fringes indicates a relative retardation of that pencil. The method was the same as in the first set, sparks being taken from prime conductor to earth at regular intervals, long and short. When the initial disturbance was over, movements of the fringes were still seen, sometimes in one direction and sometimes in the other, but not exclusively or specially at the instant of discharge. These disturbance movements were slow and generally small; and as the experiment proceeded they became very faint, and were occasionally not seen at all for a little time. As to the effect specially looked for, I need only say that in several scores

of observations, taken at different potentials, high and low, there was not a trace observed of a regular jump of the fringes at the instant of discharge. It appears, therefore, that when the plane of polarisation is parallel to the line of force, the light is neither retarded or accelerated by electric strain. The spars R and S were now turned back through 180°.

Third Set.—The same again as the first. Many observations were taken, and the former effects were obtained regularly; but they were now more striking, because of the strong contrast with the negative results of the set of observations immediately preceding. The action appeared also to be stronger than before, probably because of improved insulation. The extent of the jump, taken at every 5th turn of the plate, was now half the fringe-width; and at every 10th or 15th turn it was clearly four-fifths. I find in my notes that this large jump of the fringes impressed me here, again and again, as a thing peculiarly beautiful.

Fourth Set.—The same again as the second. The only question in this case was, whether it might still be possible, by the most careful work and under the best conditions attainable, to detect a very small jump of the fringes at the instant of discharge. Many observations were taken at high potential, some at the highest, but without a trace of effect of that kind.

Fifth Set.—The same again as the first. The results of the first and third sets were recovered regularly. Sparks were then taken, sometimes at every turn of the plate, sometimes oftener. At every spark there was a very small downward jump of the fringes, so small sometimes as to be barely caught, but quite regular and beautifully distinct.

Remarks.—The jump of the fringes was chosen as the principal object of observation, because it was never quite concealed, nor even much obscured, by the mechanical disturbance of the liquid; but I should add that the contrary motion—the gradual ascent of the fringes during the process of charging—was generally evident enough in the experiments, though not often undisturbed or quite regular in its course.

The best observations were got when the fringes happened to continue at rest through a sensible interval of time, including the instant of discharge. The contrast between the two cases was then very remarkable, especially at high potential; in the one case, the beautifully clear jump so often mentioned; in the other case, no trace of a jump in either direction, generally not even a perceptible shiver of the fringes at the instant of strongest discharge. Instances of this kind occurred not very rarely in the experiments; and there could be no contrast more striking than that between the phenomena in the two cases.

From what I know of the apparatus and its performance I am sure that no regular and abrupt retardation or acceleration amounting to as much as the *hundredth* part of an average wave-length could have escaped observation in the experiments. It will be remembered also that the jump of the fringes at high potential extended to *four-fifths* of the fringe width. With reference, therefore, to the dielectric CS_2, and the two principal vibrations parallel and perpendicular to the line of force, it appears that the regular effect of the electric strain upon one of the vibrations is a positive retardation, while upon the other vibration there is very probably no effect whatever, and certainly no effect as large as the *eightieth* part of the former.

Second Positive Dielectric: A paraffin oil, specific gravity 0·845. This liquid was far inferior to CS_2 electrically, and also as an optical medium. The method of experiment finally adopted as the best was a little different from that with CL_2. The prime conductor had its capacity enlarged by connexion with a Leyden jar; the machine was kept working at a constant rate, and the prime conductor was partially discharged, at short and regular intervals, by sparks upon the knob of the first internal conductor, which was of course discharged in each interval. The phenomenon looked for was a quick motion of the fringes at the instant of the spark; that is, at the instant of electric charging of the liquid.

(1.) Plane of polarisation of the pencil BF (through the electric field) vertical: Rise of fringes indicates relative retardation of this pencil. At the instant of the spark there was a quick upward jump of the fringes through something like one-fifth of the fringe width, generally followed by a set of large and comparatively slow disturbance-movements. In most cases also, immediately after the spark, the observer was able to detect the contrary jump quite clearly by laying his finger on the knob of the first conductor. Through a long set of observations, taken at different potentials, the upward jump of the fringes at the instant of charging was obtained with perfect regularity; and—amplitude excepted—the effect was not inferior to that in CS_2.

(2.) Plane of polarisation of the pencil BF horizontal: Rise of fringes indicates relative retardation of BF. Many observations were taken at different potentials, high and low. There were sluggish and irregular disturbance movements, great and small, but no trace of a regular jump of the fringes in one direction or the other at the instant of the spark. There could be no doubt as to the true meaning of these results. In this positive dielectric, as in CS_2, the vibration along the line of force is retarded by electric strain, and the perpendicular vibration is unaffected.

First Negative Dielectric: Oil of Colza.—This liquid also was far inferior to CS_2, especially as an optical medium. The method of

experiment followed with paraffin was retained here as the best; the first internal conductor was charged by spark from the prime conductor at regular intervals, and was put to earth for a moment in each interval.

(1.) Plane of polarisation of the pencil BF vertical: Rise of fringes indicates relative retardation of BF. The fringes were generally curved and very imperfect at the beginning of an experiment, but a few successive charges brought them, after some disturbance, into permanently good form, and then there was a quick downward jump, seen always at the instant of the spark. And, as in the contrary case of paraffin, this jump was a thing as distinct as possible from the sluggish and irregular disturbance-movements by which it was generally followed. When the spark was taken at every 10th turn of the plate, the potential was about as high as the liquid could bear, and the extent of the jump was fully one-fifth of the fringe-width. In the course of a long set of observations this downward jump of the fringes at the instant of charging was seen with perfect regularity, and always distinctly. In this case, therefore, the regular optical effect of electric strain was an acceleration.

(2.) Plane of polarisation of the pencil BF horizontal: Rise of fringes indicates relative retardation of BF. When the fringes were imperfect at starting, the effects of a few successive charges were the same as in the first case, irregular displacements and changes of inclination, the fringes generally rising and falling in their lower and higher parts till they came into permanently good form. Afterwards there were smaller disturbances always present in this case as in the former; but neither there nor here were they such as to interfere ultimately with exact observation. The experiment was carried on for some time till the liquid was well mixed and the fringes good. Many observations were then taken, some of them at highest potential, but there was no trace of a jump ever seen at the instant of the spark. In this liquid, therefore, as in carbon disulphide and paraffin, the only one of the two principal vibrations which is affected by electric strain is that along the line of force; but, as the present dielectric is of the negative class, the retardation produced is negative.

Second Negative Dielectric: Seal Oil.—From want of homogeneity this liquid was very defective optically, the image of the slit L being much deformed and sometimes broken by streaks. The defect was remedied in a good degree by strong charges given to the liquid on both sides of the second conductor. The method of experiment was the same as with oil of colza.

(1.) Plane of polarisation of the pencil BF vertical: Rise of fringes indicates relative retardation of BF. At first, the electricity produced very large displacements and deformations of the fringes, in

the midst of which there was no regular effect to be seen; but as the experiment went on, and the medium improved, the expected effect came out distinctly: a quick downward jump of the fringes at or immediately after the instant of the spark. Under good optical conditions, and at potentials high and low, the effect was perfectly regular, and was distinct and pure as that in oil of colza, though apparently not quite so large.

(2.) Plane of polarisation of the pencil BF horizontal: Rise of fringes indicates relative retardation of BF. The disturbance of the fringes was greatly reduced as the experiment went on, till at last there was nothing left but a set of slow movements, very irregular and very small, sometimes invisible. In the midst of these, as in their absence, and in a long set of observations, taken at different potentials, from low to highest, there was no trace ever seen of a jump of the fringes at the instant of the spark. It appears, therefore, that in this negative dielectric, as in oil of colza, the total optical effect of electric strain is an acceleration of the vibration which is directed along the line of force.

The conclusion to be drawn from the preceding experiments has been stated already by anticipation; but I repeat it finally in other terms as follows:—

*If light pass through an electrostatically-strained medium at right angles to the lines of force, and be represented by two component lights whose planes of polarisation are respectively parallel to the lines of force and perpendicular, then the proper and immediate optical effect of the electric strain is a change of velocity of the latter component.**

The use of the words *proper and immediate* in this statement may be thought objectionable; but some such words are required for the purpose here chiefly intended, which is to exclude those undoubtedly remote effects of electric action that appeared as disturbances in all the experiments.

IV. "On the Liquation of Silver-Copper Alloys." By EDWARD MATTHEY, F.C.S., Assoc. Roy. Sch. Mines. Communicated by Sir G. G. STOKES, F.R.S. Received February 16, 1894.

It is a well-known fact that during the solidification of certain alloys groups of the constituent metals fall out of solution, giving rise to the phenomenon called "liquation." The molecular arrangement which results from this behaviour of alloys has been investigated by many experimenters, notably by Devol, Roberts-Austen, and Guthrie. The author has also studied the behaviour of a large

* The change of velocity in the case of any positive dielectric is of course a decrease.

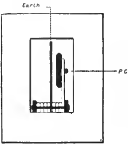

Fig 1

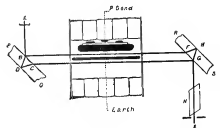

Fig 2

Fig 4.